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Galilean Electromagnetic (GEM) PIC code for highly efficient simulations of LWFA and PWFA

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A novel method for simulating wakefield acceleration in plasmas is introduced. The newly developed **GEM-PIC** code is a fully electromagnetic, three-dimensional (3D) particle-in-cell (PIC) simulation tool that leverages a Galilean transformation of variables. This transformation effectively eliminates the vast scale disparity between the laser wavelength and the typical acceleration length in wakefield setups.

Similar to established quasi-static simulation codes, GEM-PIC employs a transformation to fast and slow variables: \(\zeta = z - ct\) for the fast coordinate and \(\tau = t\) for the slow time. However, unlike quasi-static approaches, GEM-PIC retains the complete set of Maxwell's equations without approximation. This allows it to fully resolve electromagnetic wave propagation, including the laser pulse itself. Furthermore, GEM-PIC treats all particles equally and does not distinguish between beam and plasma particles, enabling a self-consistent modeling of particle trapping.

The GEM-PIC framework paves the way for **ab initio** simulations of laser pulse propagation and wakefield formation in extended plasma channels. It is also capable of modeling beam-driven wakefields and simulating the propagation of particle bunches through external magnetic fields—for instance, in transitions between plasma sections.

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